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Research on a Scientific Approach for Bus and Metro Networks Integration

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Abstract

The objective of this study was to develop and apply a 'scientific approach' for improving the integration of Beijing's metro and bus networks. Daxing Line, which is one of the five newly built metro lines opened in Beijing in 2010, was selected as a demonstration metro corridor for this methodology. A detailed public transport passenger trip matrix is developed from the Beijing public transport IC card data. According to this data, different bus service patterns were evaluated using a pivot point demand model and PT model. In the final section of the paper, the schemes are evaluated through using a set of 6 weighted indicators to decide on an optimal outcome. The bulk of the recommended service planning adjustments recommended by the study are currently being implemented in the corridor. The study concludes that the proposed approach is practical and can provide meaningful input to service planning in multi modal corridors in Chinese cities. Given the rapidly expanding metro networks in many Chinese cities, there is a large potential for replication of the approach described in the paper.

Keywords: bus; metro; network; integration; approach

1. Introduction

Beijing's rapidly growing population and economic development as well as a rapid increase in motorization have made congestion. In response, Beijing has adopted a multi-dimensional strategy to give priority to all modes of public transport. Specific actions reflecting this strategy include accelerating the

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expansion of the metro network. And metro services should be integrated with the more extensive surface transportation system, so that more direct and convenient trips can be provided and thus more riders will be attracted.

This research focuses on developing a scientific methodology to evaluate integrated service planning for bus and metro services in Beijing. They can provide an efficient and attractive transport option for the maximum number of transit users. This scientific approach will reflect the functions of:

- the metro: primary “backbone” for public transport; directly serving highest volume/trip length corridors and largest activity centers
- bus system: Basic coverage on all arterials; complimentary services in metro corridors parallel and intersecting; extending metro access beyond terminals; providing trunk services in other, lower volume (e.g., outer circumferential) corridors.

2. Selection of a Single Demonstration Corridor

In 2010, five new metro lines were opened in Beijing. There were: Changping Line, Metro 15, Yizhuang Line, Fangshan Line and Daxing Line (Fig. 1).

The first step in the study was to choose a single corridor for demonstration (Guillot, E,984). This was necessary to avoid the need to develop and analyze a large number of combinations and permutations of integration schemes in multiple corridors.

Each corridor was different in terms of its position in the topology of the metro and bus networks and roadway system, as well as its demand and performance. This study utilized a small number of factors that indicated how successful a demonstration was likely to be in the respective corridor. The factors used here were:

- Rail line construction timing and phasing (open to its extremity before the end of 2010 most highly ranked)
- Major corridor roadway congestion, especially as it effects ground public transport (the greater the better)
- Degree of physical separation between major roads and the respective rail line (the closer the higher ranked)
- Degree of duplication between current bus PT services and the rail line (the greater, the better)

If a corridor was highly ranked in all the factors relative to the others, it would be selected for analysis. If not, the corridor which did the best in the largest number of factors and ranked in the top half in all the rest would be selected, etc (Table1).

Table 1. Factor result

Line Name	Construction time	Congestion index	Road/Rail Coincidence （km）	duplication along the rail line（route）		
				Parallel	Intersect	total
Changping line	2012	3.3	2.11	17	9	26
M 15	2012	6.2	0.22	34	36	70
Yizhuang line	2010	6.5	3.56	24	14	38
Daxing line	2010	8.1	1.12	41	7	48
Fangshan line	2010	4.4	3.24	22	6	28

Fig. 1. Five metro lines

Of the five, the Daxing corridor, shown in the exhibit above was selected for analysis.

3. Development of forecast methodologies

One of the biggest challenges of this research was the development of the pivot point demand model and the PT model (Pattnalk, S.B.,1998). From them, the mode share, total ridership and every line's ridership could be derived.

At one level, the PT model was extremely disaggregate, with each bus stop serving as a zone, while the demand model was calibrated and applied at two levels, stop and zone. A base trip table was derived from IC card data at the stop level, itself a very complex task, which was then aggregated to a zonal level. A pivot point demand model using parameters derived from Beijing's regional conventional four step model was then applied to generate zonal level trip tables corresponding to each of integration schemes to be tested. These trip tables were disaggregated back down to a stop level for assignment (Fig. 2).

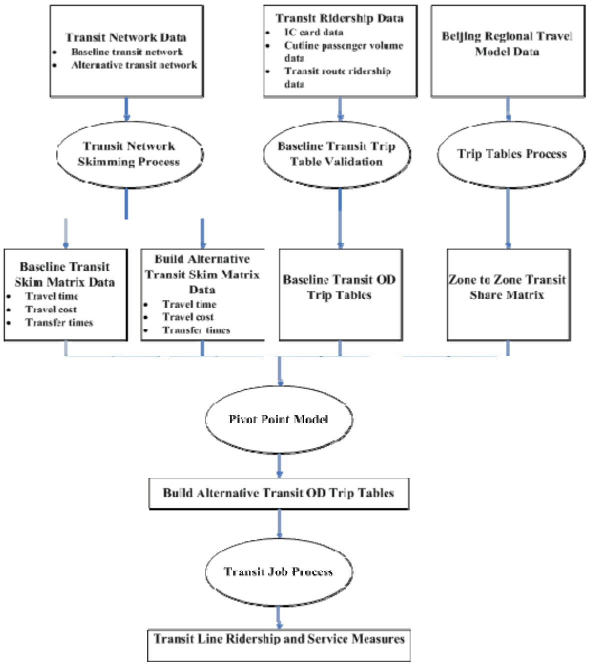


Fig. 2. Analysis flowchart

3.1. Disaggregation of traffic zones

One of the important work of the Pivot-Point Model Development is the Disaggregation of transport zones. The project covers Beijing's entire area, focusing on the 2. 5km radius areas around Daxing corridor. There are 225 transport zones in Beijing; Those 5km area either side of the Daxing Line are broken up into smaller analysis units. The division rule is to consider the setting of rail station, and land development and layout. There are 366 transport zone in the area under study after division: 156 in the corridor and 210 out the corridor.

3.2. Zone System Conversion

Another complex work is the Zone System Conversion which is mentioned above. There are 3,000 zones within the 6th Ring Road in the PT model and 366 zones in the Pivot-Point Model, as shown below. When aggregating the distance to the around stop groups and the zone area that can be covered by walking should be evaluate first, and then the travel rate from stop groups to each zone calculated.

3.3. Distribution and calibration of the model

As the travel samples may be unbalanced on time and space, the model's initial distribution result may differ from the actual situation. In order to make the model's distribution result and actual situation more coherent, we need to use the observed value to calibrate the model. VISUM provides a model calibration tool TFlowFuzzy to calibrate the model, and the process is that after the model assignment, we input the count data to TFlowFuzzy to check if the distribution result is coherent with the actual situation. The count dataincludes the survey result of bus ridership from the screen lines survey and the metro ridership from IC card data. The process is detailed as follows (Zhang, 2006).

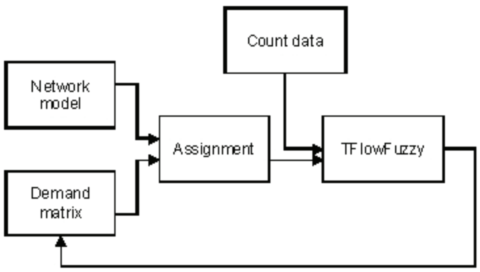


Fig. 3. The calibration process

Five supplementary screen lines were established and surveyed for the Daxing Line study. These screen line counts were used to calibrate the model results. The average difference between calibration and actual data was 7%.

3.4. Forecast Result with No Changes in Bus Network

Immediately after the opening of the metro, the total forecasted morning peak period（7:00 AM to 9:00 AM）passenger trips by public transport number 183,000, an increase of 1,500 passengers compared to the situation before the metro line opened to traffic. After metro line opening, bus passenger ridership reached 161,000, which is 23,000 trips lower than that before rail is opened, while the passenger traffic on the new subway line is predicted to be 24,000 trips.

According to the calculation of the PT model, after Daxing Line is opened, the ridership of the impacted Daxing municipal bus lines will be reduced. In particular, those lines with less passenger traffic and high route overlap will have larger passenger transfer ratio, for example, 32% of Line 841 will transfer to the subway, 43% of Line 844. And Daxing local bus connecting to Daxing Line will have ridership increase to a certain extent, such as the passenger traffic increased 22% at Daxing New Town Line 1 and 41% at Daxing New Town Line 2.

4. Development of Alternative Bus/Metro Integrative Schemes

There are almost an infinite number of ways that bus networks can be adjusted or integrated with a new metro line. The task here was to develop schemes representing a reasonable envelope within which all would lie, and then to identify a one to proceed with. After analysis of the current situation in the selected Daxing corridor, simple rules were applied to each bus route to produce comprehensive schemes forming the integrated envelope extremes. The least aggressive scheme involved eliminating or turning back only those bus routes that were completely duplicated by the Daxing line. There were few of these bus routes whose alignments were significantly changed to “feed” the metro. This scheme also included establishing several new “feeder” route connecting areas at the outer edge of the corridor to the nearest metro Daxing Line station.The other, more aggressive side of the envelope consisted of a scheme which either eliminated or turned back as many bus routes as possible. Significant diversions of many bus routes were made to” feed” various stations on the metro line. A third scheme, developed after analysis of the other two, was somewhere in between.

Based on the current line spatial distribution, combined with demand distribution, and focusing on passenger demand, we analyzed the current status and demand forecast of 41 bus routes along the Daxing corridor one by one.

5. Evaluation of Alternative Bus/Metro Integration Schemes

The biggest challenge here was to select a small number of evaluation criteria capable of differentiating among the integration schemes, and then use models to produce the criteria. The evaluating system includes six indicators chosen from three basic public transport attributes, public transport level of service, network structure and costs.

The six indicators were: Travel Time, Transfer times, Peak period Load Factor, Degree of Bus/Metro Overlap, Proportion of area within walking distance of a bus stop and Bus revenue kilometers.

Based on the model calculation, all the bus service patterns are graded(see table 2). The evaluation criteria for the “do- nothing” scenario and the recommended by the study was as follows:

Table 2. Evaluation results

Indicator Category	Evaluation Indicator	Status	do minimum	After Adjustment
service standard	Travel Time (minutes Average all zones within 5km of rail line/key zone)	41.78/60.11	40.1/55.2	40.7/54.44
	Transfer Times (5km/key zone)	0.83/1.53	0.82/1.60	0.81/1.63
	Peak period Load Factor	38%	43%	51%
network structure	Degree of Bus/Metro Overlap	4.84	4.84	4.67
	Bus stations 500 meters coverage	62%	72%	74%
operating costs	Bus revenue kilometers (vehicle km / day)	15059	13756	12684

The fuzzy model (Chien.S., 2002) is used here to evaluate different scenarios. The model used is described as below:

$$B = (b_1, b_2, \cdots b_m) = A \cdot R = (a_1, a_2, \cdots a_n) \cdot \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \quad (1)$$

$$W = B \cdot V^T \quad (2)$$

V - Evaluation vector. Evaluation results are divided into" very good"、"good"、"fair"、"poor"、"very poor", presence as vector: V=(2.1.0.-1.-2)

A - weighted scores

r_{ij} - each indicator is measured in five grades, r_{ij} indicates the percentage of indicator i being graded as j among all the experts.

R - Membership matrix, formed by r_{ij}

Through this grading system, each indicator is weighted as 0.3, 0.2, 0.2, 0.05, 0.05 and 0.2 respectively. The Evaluation Vector is demonstrated in Table 3.

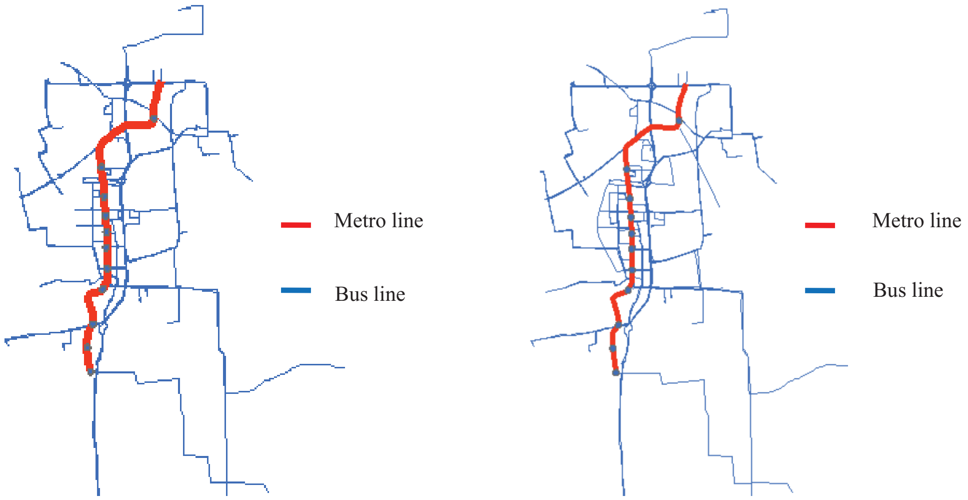
Table 3. Membership matrix

		very good	good	fair	poor	very poor
Do nothing	Travel Time	0.3	0.2	0.3	0.1	0.1
	Transfer Times	0.4	0.1	0.1	0.2	0.2
	Peak period Load Factor	0.1	0.2	0.4	0.1	0.2
	Degree of Bus/Metro Overlap	0.2	0.1	0.2	0.3	0.2
	Bus stations 500 meters coverage	0.3	0.1	0.2	0.2	0.2
	Bus revenue kilometers	0.1	0.1	0.2	0.2	0.4
Do minimum	Travel Time	0.4	0.2	0.3	0.1	0
	Transfer Times	0.3	0.3	0.3	0.1	0
	Peak period Load Factor	0.5	0.5	0	0	0
	Degree of Bus/Metro Overlap	0.3	0.2	0.2	0.2	0.1
	Bus stations 500 meters coverage	0.5	0.5	0	0	0
	Bus revenue kilometers	0.3	0.3	0.4	0	0
After adjustment	Travel Time	0.5	0.3	0.2	0	0
	Transfer Times	0.2	0.3	0.2	0.1	0.2
	Peak period Load Factor	0.5	0.5	0	0	0
	Degree of Bus/Metro Overlap	0.5	0.4	0.1	0	0
	Bus stations 500 meters coverage	0.4	0.3	0.2	0.1	0
	Bus revenue kilometers	0.4	0.4	0.2	0	0

Based on fuzzy comprehensive evaluation method, the status score is 0.045, the "do minimum" scheme is graded as 1.005, while the score for the recommended adjustment program score is 1.09, indicating that after adjustment, service customer performance, and operating costs are all improved.

6. Identification of recommended scheme

Based on the analytical results, the recommended scheme is as follows: Add four new Feeder Lines; Eliminate one overlapping bus route ; Truncate five bus routes for the redundant parts (Fig. 4).



(a) Before adjustment (b) After adjustment

Fig. 4. Bus routes network structure adjustment

7. Conclusions

This research studied the status and future demand of bus routes along the Daxing Metro line, and proposed a ‘scientific approach’ to identifying the best plan for adjusting bus service in the corridor. The proposed scenario has been approved by the Beijing Municipal Commission of Transport, and was partially implemented in the year 2010.

This project is innovative for developing a method for evaluating service changes in a multi model transport corridor that weigh competing objectives against one another including service side characteristics such as bus level of service, bus route structure, operational cost as well as demand side variables of total travel time and total number of transfers. By including a mix of variables, the methodology provides a way to quantify the interest of government, public transport riders and the bus company order to achieve the best optimization.

The study concludes that the proposed approach is practical and can provide meaningful input to service planning in multi modal corridors in Chinese cities. Given the rapidly expanding metro networks in many Chinese cities, there is a large potential for replication of the approach described in the paper.

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